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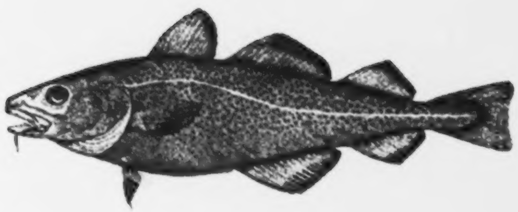
Maritimes Region

Canadian Science Advisory Secretariat
Science Advisory Report 2011/034

RECOVERY POTENTIAL ASSESSMENT (RPA) FOR THE SOUTHERN DESIGNATABLE UNIT (NAFO DIVS. 4X5Yb and 5Zjm) OF ATLANTIC COD (*GADUS MORHUA*)



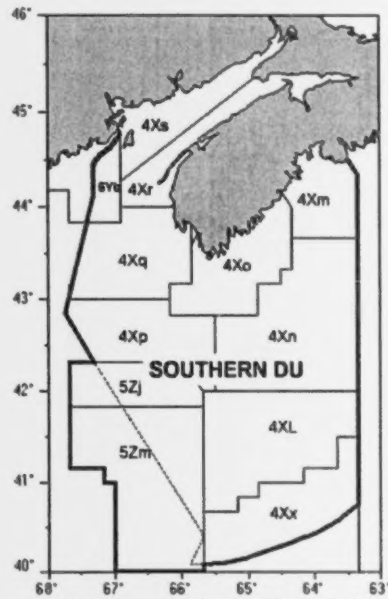


Figure 1: Southern designatable unit (NAFO Divs. 4X5Yb and 5Zjm)

Context

In its 2003 assessment of Atlantic Cod, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Maritimes designatable unit (DU) Special Concern. In April 2010, COSEWIC re-assessed Atlantic Cod. In this assessment the Maritimes DU was split into two populations, the Laurentian South DU and the Southern DU. The Southern DU was designated Endangered, a higher risk category than Special Concern, due to the significant decline in abundance and evidence of an unexplained increase in natural mortality in the 4X portion of the DU.

A recovery potential assessment (RPA) was introduced by DFO Science to provide the information and scientific advice required to meet various requirements of the Species at Risk Act (SARA), including decisions regarding the listing of Southern DU cod under the Act and developing a recovery strategy.

This science advisory report describes the status of cod populations in the Northwest Atlantic Fishery Organization Divisions 4X and the Canadian portion of 5Yb (Southern Scotian Shelf and Bay of Fundy) and 5Zjm (Eastern Georges Bank). These populations constitute the Southern DU. Historic population trajectories are described and the populations are projected into the future to assess the probability of achieving recovery targets assuming that current productivity conditions were to persist in the future. This scientific advice also addresses the major threats to the survival and recovery of Southern DU cod and the limiting factors. The measures that can help its recovery are listed.

SUMMARY

- Cod in the Southern designatable unit (DU) are assessed as two separate management units: Southern Scotian Shelf and the Bay of Fundy (NAFO Div. 4X and the Canadian portion of 5Yb), and eastern Georges Bank (NAFO Div. 5Zjm).

- The abundance of cod in the Southern DU has declined in number and biomass since the early 1990s. Trends differ between the two components in the Southern DU, with cod numbers in 5Zjm stabilizing at low levels over the past decade, while continuing to decline in 4X5Yb.

- The demersal juvenile stage (4 – 35cm long) is the most habitat-dependant period in the life-cycle of Atlantic Cod. Physical disturbance of structural components of habitat can reduce its value and increase mortality of juvenile cod. Existing data lack the spatial resolution required to evaluate the amount of suitable habitat available to demersal juveniles and whether it has changed in the past three generations, especially in the offshore. However, there is no indication that the amount of suitable habitat is currently limiting recovery of cod in this DU.

- Within the Southern DU, the area of occupancy for cod declined slightly in the 1990s but appears to be stable since 2001. Despite the slight decline in calculated area of occupancy, the range and overall distribution of cod within the Southern DU has not changed since the 1970s.

- The structure of cod populations in the Southern DU is complex, involving seasonal migration patterns, mixing grounds and some exchange between putative stocks. However, there is no evidence of a decrease in the number of populations.

- Natural mortality of Div. 4X5Yb cod aged 4 years and older (4+) is estimated to be unusually high (0.76 for 1996 to 2008), whilst natural mortality of Div. 5Zjm cod aged 6 years and older (6+) is also elevated (0.5 for 1994 to 2009).

- Average recruitment in the Southern DU stocks has decreased to less than half of the pre-1992 level. Recruitment has generally been higher for 4X5Yb cod when ages 3+ biomass has exceeded 25,000t and for 5Zjm cod when ages 3+ biomass has exceeded 30,000t. In recent years, biomass has remained below these values and recruitment has been poor.

- Conservation limit reference points (LRPs) have been calculated for 4X5Yb and 5Zjm cod, based on Beverton-Holt stock recruitment models. The Precautionary Approach (PA) reference point, B_{lim}, was calculated as 24,000t for cod in Div. 4X5Yb and 21,000t for Div. 5Zjm. Estimated 4X5Yb spawning stock biomass (SSB) has been below the LRP since 2002 and was estimated to be 10,600t at the beginning of 2009. Estimated 5Zjm cod SSB has been below the LRP since 1994 and is currently estimated to be 9,260t.

- Projections were undertaken for both stocks and at the DU level. Future productivity conditions are very uncertain. Thus, these projections should not be interpreted as forecasts of future stock status because they depend on assumptions about future productivity and fishing mortality. The probability of current conditions continuing for a long period of time is unknown. These projections are explorations of the consequences of particular productivity assumptions.

- If current productivity conditions were to persist in the future, projections of the abundance and biomass of cod in 4X5Yb and 5Zjm indicate the population is expected to increase, even with moderate fishing (i.e. to the level of the established fishing mortality threshold, F_{ref}).

- For 4X5Yb cod, with no fishing there is a greater than 95% probability of SSB being at or above the LRP of 24,000t by 2020. Fishing at half the current fishing mortality reference level there is a greater than 95% probability of SSB being at or above the LRP by 2033 and the probability of SSB being at or above the LRP within 36 years when fishing at the reference level of 0.2 is 72%.

- For 5Zjm cod, with no fishing there is a greater than 95% probability of SSB being at or above the LRP by 2028. Fishing at half the current reference level there is a greater than 95% probability of SSB being at or above the LRP by 2033 and the probability of SSB being at or above the LRP within 36 years when fishing is at the reference level of 0.18 is 82%.

- Projections of the combined mature abundance of the 4X5Yb and 5Zjm stock components indicate that the population is expected to increase under current productivity conditions over the next 36 years.

- The major potential sources of mortality identified for Southern DU cod were natural mortality (including seal predation), along with fishing above F_{ref}, discards and bycatch.

- Reductions in fishery removals, at least to the level of F_{ref}, and bycatch mortality are the only identified mitigation measures for which the increases in survivorship can be calculated.

BACKGROUND

Rationale for Assessment

Based on the decline in abundance of mature individuals over the last three generations of the Southern designatable unit (DU) of Atlantic Cod (approximately 64% for the DU as a whole) and the observation that the decline was continuous, the DU was designated as Endangered in April 2010 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

As part of this assessment process, scientific information is needed to support the development and assessment of social and economic cost and benefits of potential management scenarios for recovery to better inform public consultations and to support other entities involved in the decision of whether to add the species to Schedule 1 of the SARA. If required, the information will be used to develop a recovery strategy.

Species Biology and Ecology

Atlantic Cod (*Gadus morhua*) is a bottom dwelling North Atlantic fish. Cod range from Georges Bank to northern Labrador in the Canadian Atlantic. There are several concentrations of cod within this range, including those on the southern Scotian Shelf, Bay of Fundy and eastern Georges Bank in NAFO Divisions 4X, the Canadian portion of 5Yb and 5Zjm.

The structure of cod populations in the Southern DU is complex, involving seasonal migration patterns and mixing grounds, with some exchange between putative stocks. Although several localized populations may exist, evidence suggests three main concentrations of cod within this

DU: Southern Scotian Shelf, Bay of Fundy/Gulf of Maine and eastern Georges Bank. Tagging has shown some directional mixing between 4X and 5Zjm but current agreements for cod stock management between Canada and USA assume no significant exchange between Georges Bank and 4X. Generally, cod tagged in the Bay of Fundy and those tagged in eastern 4X5Yb exhibit little mixing, except for those found near the boundary between the two areas. Given these factors, precise delimitation of populations within the Southern DU is challenging and the possibility of over-exploiting some components of the resource through concentration of the fishery remains a concern.

Juvenile cod are widespread in the area. While they tend to be more abundant in shallow coastal areas, they are also found on off-shore banks, particularly on Georges Bank, and have been caught as deep as 250m in the Fundian Channel. They are more common in areas with complex bottom structure and vegetation. Juvenile cod feed on a wide variety of invertebrates and, as they grow, include fish in their diet.

Seasonal movements associated with spawning occur and a number of spawning areas exist in this management area. Cod in this area reach on average 53cm (21 inches) by age 3 years and increase to 72cm (29 inches) by age 5 and 110cm (43 inches) by age 10. Growth rates, however, vary, with more rapid growth noted for cod in the Bay of Fundy. Age at first reproduction generally occurs at 2 to 3 years and individuals tend to spawn several batches of eggs during a protracted spawning period.

Southern Designatable Unit

Cod in the Southern Designatable Unit (DU) are assessed as two separate management units: Southern Scotian Shelf and the Bay of Fundy (NAFO Div. 4X and the Canadian portion of 5Yb), and eastern Georges Bank (NAFO Div. 5Zjm). As the 5Z stock is transboundary, it is managed jointly by Canada and the USA. The Southern DU spans waters extending from southern Nova Scotia and the Bay of Fundy, to eastern Georges Bank (Figure 1). The most recent analytical assessment of Div. 4X5Yb cod was conducted in February, 2009, whilst the most recent analytical assessment of Div. 5Zjm cod was conducted in July, 2010.

ASSESSMENT

Historic and Current Abundance and Trends

The abundance of cod in the Southern DU has declined in number and biomass since the early 1990s. Trends differ between the two components in the Southern DU, with cod numbers in 5Zjm stabilizing at low levels over the past decade, while continuing to decline in 4X5Yb (Figure 2).

The 4X5Yb stock status evaluation (virtual population analysis - VPA) shows a general decline in numbers and biomass since 1980 (Figure 2), with the 2008 mature 3+ spawning stock biomass of 10,600t (5.2 million individuals) being the lowest observed in a time series dating back to 1948.

Stock status evaluations for 5Zjm (VPA) indicate a substantial decline in adult population numbers and biomass in the mid 1990s, after which the stock has remained consistently at a low level (Figure 2). The abundance of cod in Div. 5Zjm remains below pre-1994. Mature biomass at the beginning of 2010 was estimated at 9,260t (3.4 million individuals).

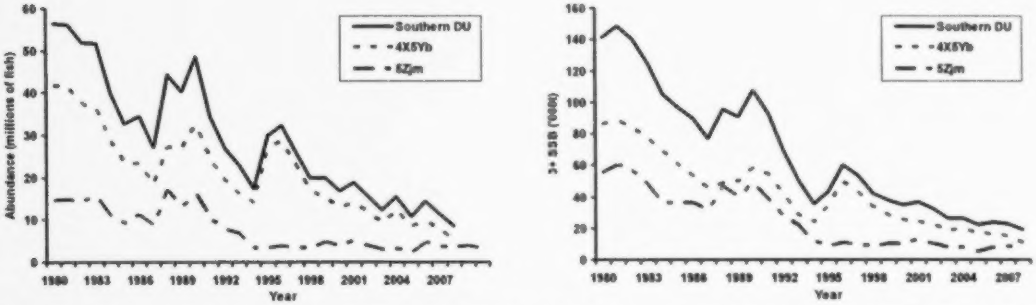


Figure 2: Mature (3+) abundance (left) and spawning stock biomass (right) for cod in NAFO Divs. 4X5Yb, 5Zjm and the Southern DU.

Historic and Current Distribution and Trends

Within the Southern DU, the area of occupancy for cod declined slightly in the 1990s, but appears to be stable since 2001 (Figure 3). The majority of the decline is attributed to decreases in area of occupancy for 4X5Yb cod, as data from 5Zjm show no trend. Despite the slight decline in calculated area of occupancy, the range and overall distribution of cod within the Southern DU has not changed since the 1970s. Survey catches continue to span all strata, with general distribution and highest catches similar to those seen in previous years (Figure 4).

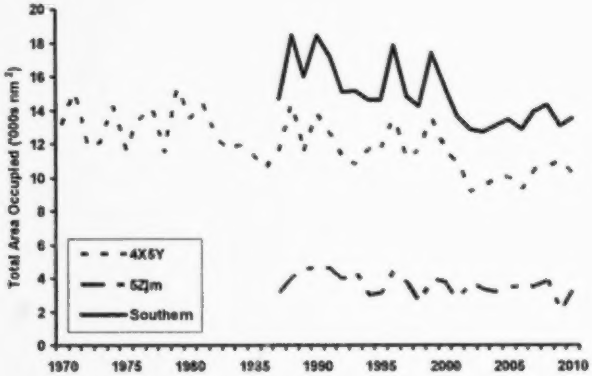


Figure 3: Area of occupancy for cod in NAFO Divisions 4X5Yb and 5Zjm and the Southern DU from the DFO summer (4X5Yb) and winter (5Zjm) surveys. (nm represents nautical miles.)

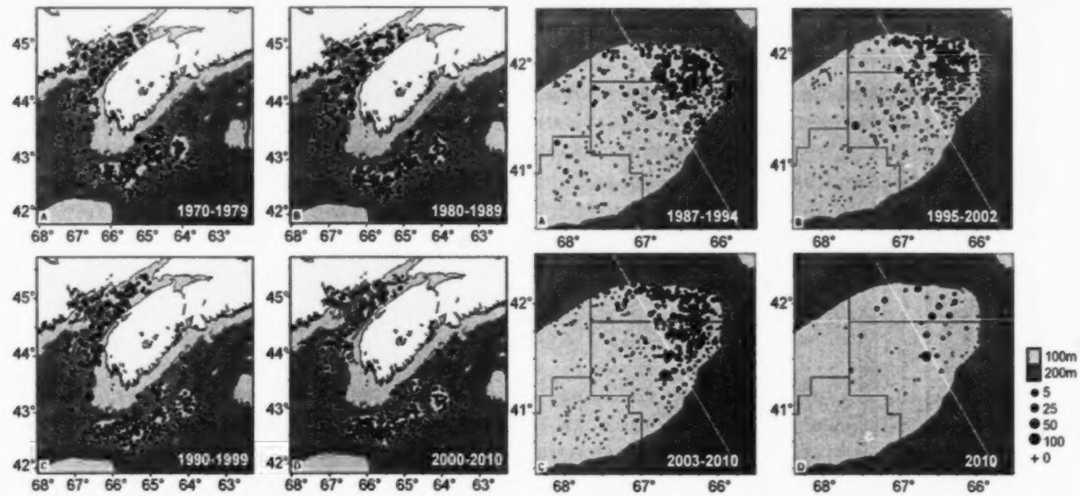


Figure 4: Observed fish counts in NAFO Division 4X5Yb from DFO Ecosystem Summer Surveys (left four panels) and in NAFO Div. 5Zjm from the DFO Winter Survey (right four panels).

Stock Structure

The structure of cod populations in the Southern DU is complex, involving seasonal migration patterns and mixing grounds, with some exchange between putative stocks. Although several localized populations may exist, evidence suggests three main concentrations of cod within this DU: Southern Scotian Shelf, Bay of Fundy/Gulf of Maine and eastern Georges Bank. Tagging has shown some directional mixing between 4X and 5Zjm but current agreements for cod stock management between Canada and USA assume no significant exchange between Georges Bank and 4X. Generally, cod tagged in the Bay of Fundy and those tagged in eastern 4X5Yb exhibit little mixing, except for those found near the boundary between the two areas. Given these factors, precise delimitation of populations within the Southern DU is challenging, but there is no evidence of a decrease in the number of populations.

Life-History Parameters

Natural Mortality, *M*

Natural mortality of Div. 4X5Yb cod, aged 4 years and older (4+), is estimated to be unusually high (0.76 for 1996 to 2008, VPA). Natural mortality of Div. 5Zjm cod aged 6 years and older (6+) is also elevated (0.5 for 1994 to 2008, VPA).

Total Mortality, *Z*

Total mortality for cod in both Divs. 4X5Yb and 5Zjm shows little or no decline over the last three decades. Although fishing mortality decreased dramatically in the 1990s, this decrease was offset by a rise in natural mortality, particularly in Div. 4X5Yb (Figure 5), resulting in high estimates of *Z* for the Southern DU (Figure 6).

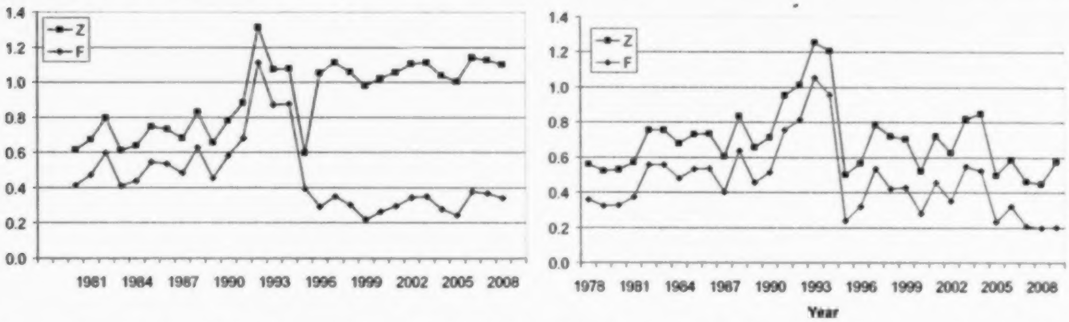


Figure 5: Total mortality (Z) and Fishing Mortality (F) estimates for Divs. 4X5Yb cod (left) and 5Zjm (right).

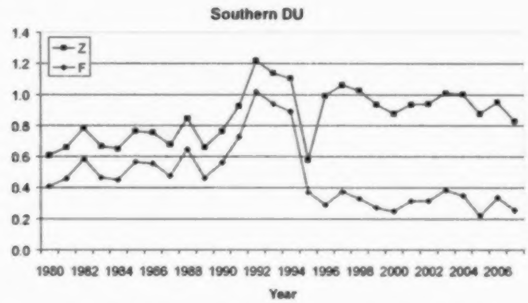


Figure 6: Total mortality (Z) and Fishing Mortality (F) estimates for the Southern DU.

Maturity and Generation Time

The average age at 50% maturity for stocks in this DU is 2.5 years. Growth is much faster and maturity occurs much earlier than in the other Canadian cod stocks. Generation time for the stocks is estimated to be 7.5 years, yielding a three-generation time period of 22.5 years.

Growth, Weight-at-Age and Condition

Div. 4X5Yb

There are growth differences between cod from the Bay of Fundy (4X West: Divs. 4Xqrs5Yb) and the Southwest Scotian Shelf (4X East: Divs. 4Xmno) with cod in the Bay of Fundy growing at a faster rate. For younger ages (less than 6), there are no strong trends in weights-at-age for commercial landings from both the Bay of Fundy and the Southwestern Scotian Shelf (Figure 7). Given the very low numbers in the catch of ages 6 and above, the weights-at-age of these older fish are likely not reliable.

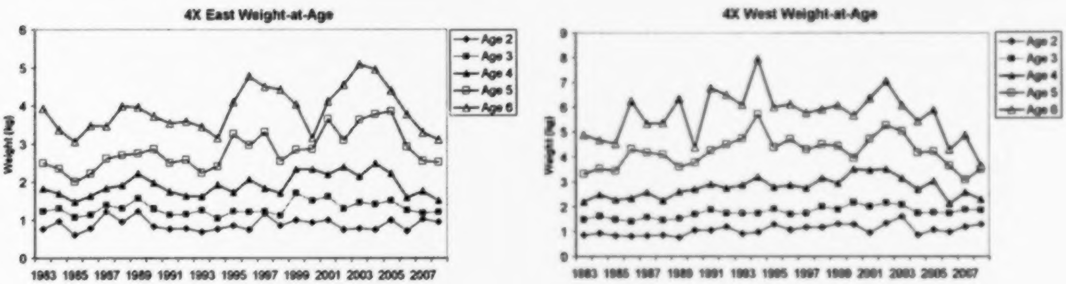


Figure 7: Weights-at-age by region for NAFO Division 4X5Yb cod caught in the commercial fishery.

Lengths-at-age for 4X cod from the DFO spring research vessel survey are stable for both Eastern and Western regions of 4X5Yb (Figure 8). The very low numbers of fish for some ages results in high interannual variability for older ages.

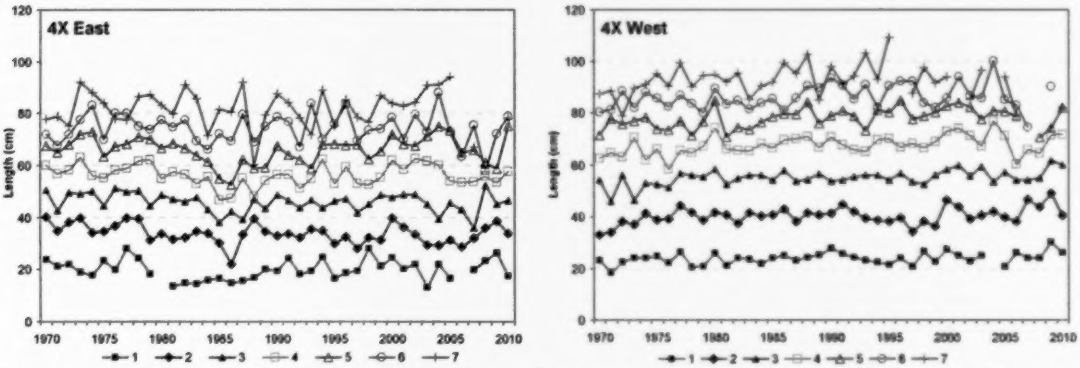


Figure 8: Lengths-at-age by region for NAFO Division 4X5Yb cod caught in the DFO spring Research Vessel survey.

There is no trend in condition for cod in 4X West but the condition factor has declined for cod in 4X East (Figure 9).

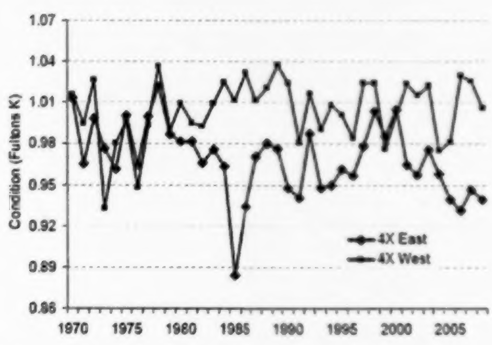


Figure 9: Condition factor (Fultons K: weight/length^3) for NAFO Division 4X5Yb cod by region.

Div. 5Zjm

Fishery weights-at-age show a declining trend for ages 5+ starting in the early 1990s (Figure 10, left panel). The average beginning of year weights-at-age derived from the DFO and the USA National Marine Fisheries Service (NMFS) spring surveys also display a declining trend since the early 1990s, but there was some improvement in 2010 for some ages (Figure 10, right panel).

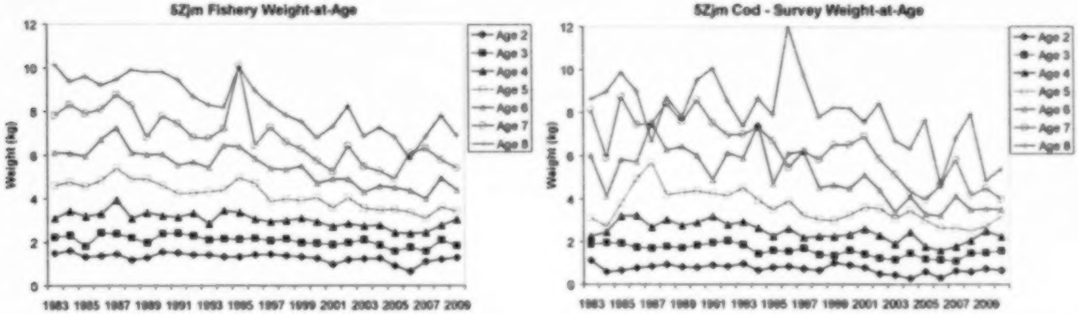


Figure 10: Weights-at-age by region for NAFO Division 5Zjm cod caught in the commercial fishery (left panel) and in the DFO and NMFS spring surveys (right panel).

Cod condition, derived from the DFO survey and measured as average weight at length at three representative length groupings, shows no notable trend (Figure 11).

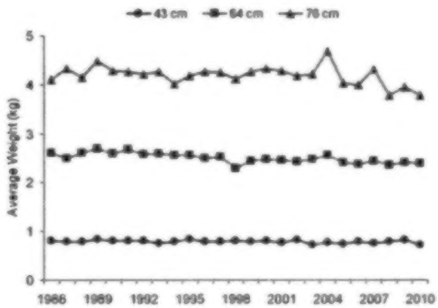


Figure 11: Condition, measured as average weight at three representative length groupings, for 5Zjm cod from the DFO spring survey.

Recruitment

Recruitment above 15 million fish was common for Div. 4X5Yb cod in the 1980s but since the 1992 year-class, no recruitment has approached this level. Recruitment has generally been higher when ages 3+ biomass exceeded 25,000t, but in recent years with biomass less than this value, recruitment has been poor (Figure 12).

Recruitment for 5Zjm cod has been poor since the early 1990s (≤ 5 million fish). Recruitment has generally been higher when ages 3+ biomass exceeded 30,000t and the number of recruits per spawner has not increased in recent years when the biomass has been low (Figure 12).

Average recruitment in the Southern DU stocks has decreased to less than half of its pre-1992 level, with periodic strong year-classes occurring intermittently for each stock (Figure 13).

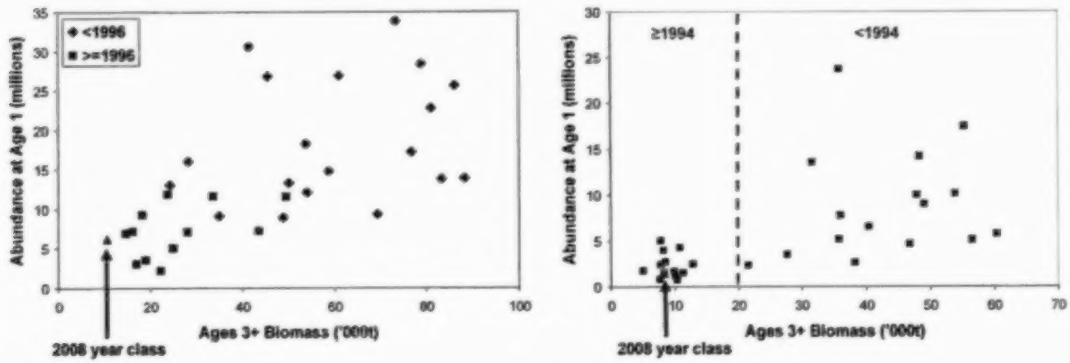


Figure 12: Relationship between adult biomass (ages 3+) and recruits at age 1 for Divs. 4X5Y cod (left) and 5Zjm cod (right).

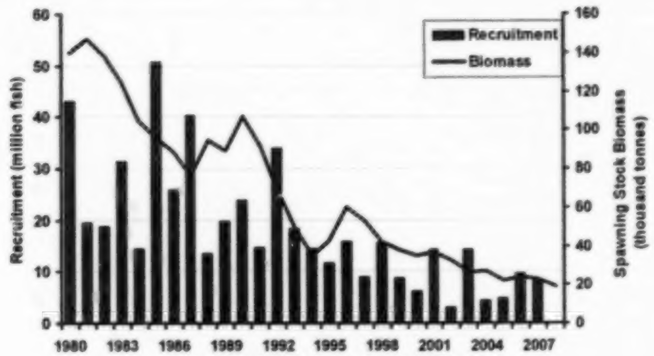


Figure 13: Recruitment (age 1) and spawning stock biomass (age 3+) of Southern DU cod.

Habitat Requirements and Suitability

Residence Requirement

The *Species at Risk Act* 2(1) defines a residence as a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating.

Cod do not have any known dwelling-place similar to a den or nest during any part of their life-cycle. Therefore, the concept of residence does not apply.

Habitat Properties

Habitat use by Atlantic Cod varies significantly by life stage and size. Latitudinal gradients in development rates (spawning times, egg development rates, and growth rates of all life stages), influence habitat use patterns in the species. Physical habitat associations are the strongest at the demersal juvenile stage (4-35 cm long).

Eggs and Larvae

Egg and larval distributions are determined by the spawning locations of adult cod and subsequent action by prevailing oceanographic currents and non-density dependant forces. Eggs are typically found in the upper surface layers of the water column. There is no evidence to suggest that they are associated with particular physical habitat features.

Juveniles

Cod assume more active control of their movements at the pelagic juvenile stage. It remains unknown to what extent individuals exhibit directional movements which might determine where they settle to the seabed. Prevailing evidence suggests that oceanographic currents and retention mechanisms have a dominant role on distribution.

The demersal juvenile stage is the most habitat-dependant period in the life-cycle of Atlantic Cod. Association with specific habitat features and habitat components is of greater importance in demersal juveniles after settlement to the seabed. In western Atlantic waters, settlement occurs in both coastal and offshore locations in the southern portion of the range, whereas in the north it occurs predominantly in coastal areas. Within the Southern DU settlement locations vary from coastal areas in the Bay of Fundy and the southern shore of Nova Scotia, to offshore banks such as Browns or Georges Banks. It appears that area of settlement may be related to temperature conditions which affect growth.

Within these broader geographic considerations, demersal juvenile cod associate with seabed habitats which provide cover from predators - physically complex habitats among those available. There is evidence to suggest that structurally complex habitat reduces mortality rate and is preferred by demersal juveniles. Inshore, vegetation - eelgrass and macroalgae - is important. In both inshore and offshore areas, pebble-gravel and rock-boulder areas within a patchy marine landscape are significant habitats for demersal juveniles.

There is evidence that juvenile cod do saturate local habitat and their densities affect recruitment to subadult life stages. Therefore, the amount of habitat likely defines an upper threshold carrying capacity within the life stage.

Adult

Evidence of habitat use by adult Atlantic Cod is limited to seasonal movements or migratory patterns typically following specific thermal ranges or oxygen levels near the seabed. Although they are widely distributed throughout the Southern DU, adult cod in this DU are associated with structurally complex seabed habitat with high prey concentrations.

Overwintering areas tend to be in deeper warmer waters.

Spawning Adults

Over the species range, spawning cod have been observed both in the offshore and inshore waters in large aggregations at all times of the year depending on location. Most spawning occurs in a two to three month long period, which may be specific to location. Individuals are batch-spawners. There is little consistency in spawning depth among areas. There is no correlation of location or timing of spawning to temperature. There is evidence for coupling of spawning times with high secondary productivity.

The specific seabed habitat features that influence affinity to a specific area are not well known. Spawning locations are thought to be associated with oceanographic features, such as gyres or currents, which retain eggs and larvae or distribute them to locations where conditions are generally good for the early life-history stages. Specific spatial locations, which are stable in time, suggest there are distinctive features about these locations leading spawners to choose them repeatedly. We do not currently know what constitutes "the habitat" for spawning cod, other than it quite often happens in the same place annually.

In the Southern DU, spawning is distributed broadly, both geographically and seasonally. Spring spawning tends to be spread throughout the DU, with some concentration on Browns Bank and eastern Georges Bank; fall spawning (October – December) tends to occur along the coast of Nova Scotia. Specific spawning habitat preferences for cod within the Southern DU are unknown, as spawning occurs in waters ranging from tens to hundreds of metres in depth.

Spatial Extent of Habitat

The geographic distribution of Atlantic Cod ranges from Cape Hatteras, North Carolina to Greenland on the western Atlantic and the Barents Sea south to Spain and Portugal on the eastern Atlantic. Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating that some amount of suitable habitat exists within this range. However, very little information is currently available at the appropriate spatial resolution to identify the extent of the habitat available to demersal juvenile Atlantic Cod – such as gravel and cobble, eelgrass beds or macroalgae – especially in the offshore. There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

Activities that Might Threaten Habitat

In general, potential for anthropogenic disturbance is highest in the coastal zone and with proximity to human population centers and industrial activity. Natural mortality of demersal juveniles can increase significantly with loss of habitat structure. Habitat alteration in the form of physical disturbance to structural components of habitat such as complex living habitat (e.g., corals, eelgrass and macroalgae) and some physical seabed features (e.g., fine scale geological bedforms) can reduce its function of providing cover from predators, therefore decreasing its value.

Mobile bottom-contact fishing gears do have impacts on benthic populations, communities, and habitats. The effects are not uniform, but depend on at least the specific features of the seafloor habitats, including the natural disturbance regime; the species present; the type of gear used, the methods and timing of deployment of the gear, and the frequency with which a site is impacted by specific gears; and the history of human activities, especially past fishing, in the area of concern.

Other gears, including those that do not contact the bottom, may still have an effect but the severity of any impact will depend on the nature of the impact (i.e. what is impacted and in what way); the location and scale of the fishery and how the gear is rigged, deployed, and retrieved.

Eutrophication is a threat in areas of the nearshore and also in some areas of the inshore. Eelgrass beds and macroalgae can be impacted by anthropogenic eutrophication, sedimentation, and contaminants.

Oil and gas development may cause physical disturbance or contamination of habitat.

Impact of Potential Habitat Changes

Limitations in the quantity of habitat available and interannual variation in predator and prey abundance can create bottlenecks to demersal juvenile survival.

Juvenile cod mortality rate is very high in non-complex habitat, compared to complex habitats nearby. The ecological significance of complex habitat on survival of demersal juvenile cod cannot be overstated. Complex habitat represents a buffering effect on populations, especially at low abundance. Evidence that demersal juvenile cod can attain a carrying capacity limit has been demonstrated at local scales in coastal waters; however, this appears to be rare and is unlikely to be a common occurrence across an entire DU.

Reduced landscape complexity in eelgrass beds leads to reduced demersal juvenile densities and carrying capacity within habitat. The impact of reduced landscape complexity for other habitat components is unavailable.

Spatial Configuration Constraints

Spatial configuration constraints such as connectivity and barriers to access are not a current limiting factor for Atlantic Cod recovery.

Amount of Suitable Habitat

Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating that some amount of suitable habitat exists within this range. However, very little information is currently available at the appropriate spatial resolution to identify the extent of the habitat available to demersal juvenile Atlantic Cod – such as gravel and cobble, eelgrass beds or macroalgae – especially in the offshore. There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

Feasibility of Habitat Restoration

It is technically feasible to undertake restoration of coastal habitat in localized areas. However, there is no indication that such restoration is required for population recovery.

Habitat restoration to higher values would likely be focused in shallow environments (e.g., coastal environment). Introduced materials (e.g., rocky reefs) and restored shoreline and eelgrass restorations and transplants have been successful in other countries and also in Canada.

Natural expansion of some vegetated habitat is known to be accompanied by increased demersal juvenile density. Therefore, it is possible to consider such options on small local scales.

Risks Associated with Habitat "Allocation" Decisions

The degree to which a habitat can be defined as a discrete area with clear edges or a gradient of features in the marine environment has not been identified. The associated risks of habitat allocation decisions have not been evaluated for Atlantic Cod. However, as noted earlier, there is no indication that the amount of suitable habitat is currently limiting recovery of cod.

Impact of Threats on Quality and Quantity of Available Habitat

Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating that some amount of suitable habitat exists within this range.

Habitat alteration, especially physical alteration or loss of structurally complex seabed habitat will reduce its value. Threats to cod habitat include physical disturbance to complex living habitat and physical seabed features, eutrophication, invasive species and shoreline development.

Natural mortality of demersal juveniles can increase significantly with loss of habitat structure. Habitat alteration in the form of physical disturbance to structural components of habitat such as complex living habitat (e.g., corals, eelgrass and macroalgae) and some physical seabed features (e.g., fine scale geological bedforms) can reduce its function of providing cover from predators, therefore decreasing its value. Due to the current lack of knowledge of distribution and quantity of structurally complex habitat, especially in the offshore, we have little understanding of how much these habitats may have been altered by human and natural disturbances in the past. The specific effects of any particular threat on productivity of cod habitat are even less clear. There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

The permanent loss of some habitat components will have a disproportionate negative effect on cod populations. Eelgrass is a DFO-Ecologically Significant Species. It is known to be important in near shore areas for small demersal juvenile cod in much of its range. The impact of loss of this habitat is known to be high. Impacts of possible losses for other habitat components have not yet been determined.

Fishing gears and eutrophication also affect the quality and quantity of available habitat as described under the section above ' Activities that Might Threaten Habitat'.

Invasive species present a significant local threat in some areas in which they have been observed. Invasive green crab (*Carcinus maenas*) is a known threat in shallow coastal waters. The species can destroy eelgrass beds by uprooting the plants. Other invasive species can overgrow marine vegetation, reducing its function of providing cover from predators, therefore decreasing its value. There have been no specific threats to cod habitat identified in offshore areas.

SARA and Management Considerations

Limit Reference Point

The conservation limit reference point (LRP) is the SSB below which the stock is considered to have suffered serious harm and the probability of good recruitment is low.

LRP values for both components of the Southern DU were determined at the Atlantic Cod Framework Meeting on Assessment Models, Medium-term Projections, Reference Points held in Moncton, December 6 to 8, 2010. The PA reference point, B_{lim}, was calculated as 24,000t for Div. 4X5Yb and 21,000t for Div. 5Zjm based on Beverton-Holt stock recruitment models.

Projections at Current Productivity

Each of the components of the Southern DU (Divs. 4X5Yb and 5Zjm cod) were projected forward over 36 years, which represents more than five generations for this DU. Long term projections and associated uncertainties are highly sensitive to the recruitment input data. Stock-recruit information from 1980 to the present was used for 4X5Yb projections and from 1978 to the present for 5Zjm projections since the recruitment data for the recent time period (since 1994) is restricted by the narrow range in biomass. These projections were used to estimate the probability of achieving the LRPs, assuming current productivity conditions persist in the future.

In addition to stock-specific projections, combined mature abundance was projected ahead 36 years for the Southern DU (median projection and percentiles). For each year of the projection, the probability of being higher than the combined mature abundance 36 years earlier was calculated. A high probability of this occurring is offered here as an indication that a DU (or a species) may no longer be at risk and would require further evaluation. For the Southern DU, this comparison can only start in 2016, as it can only occur 36 years after the earliest year in the historical time series.

Future productivity conditions are very uncertain. Thus, these projections should not be interpreted as forecasts of future stock status because they depend on assumptions about future productivity and fishing mortality. The probability of current conditions continuing for a long period of time is unknown. These projections are explorations of the consequences of particular productivity assumptions.

Div. 4X5Yb Cod

The 36 year projection for cod in 4X5Yb indicates that this component will likely increase to a level above the Precautionary Approach LRP of 24,000t. With no fishing, the median for the projection of 3+ biomass of 4X5Yb cod is expected to reach the LRP of 24,000t around 2014 (2.5^{th} percentile 2011, 97.5^{th} percentile 2020; Figure 14, top left panel). With fishing at the reference level for this stock (F_{ref}=0.2), the biomass of 4X5Yb cod is also expected to increase but at a slower rate, and the median is expected to reach the LRP around 2025 (2.5^{th} percentile 2011, 97.5^{th} percentile >2050; Figure 14, top right panel). With fishing at half of F_{ref} (F=0.1), the biomass of 4X5Yb cod is expected to increase at a rate between F=0 and F=0.2 and the median is expected to reach the LRP around 2016 (2.5^{th} percentile 2011, 97.5^{th} percentile 2033; Figure 14, bottom left panel). Productivity remains low compared to earlier years, due to the high natural mortality. The population will not sustain fishery removals of the magnitude seen prior to 1994 unless natural mortality declines.

The probability that SSB is less than the LRP is shown in the lower right panel of Figure 14. With no fishing (F=0), there is a greater than 95% probability of SSB being at or above the LRP of 24,000t by 2020 (50% probability of it occurring by 2013). The probability of SSB being at or above the LRP within 36 years when fishing at the reference level of 0.2 is 72%, with 50% probability of it occurring by 2025. For fishing at half the current fishing mortality reference level (F=0.1), there is a greater than 95% probability of SSB being at or above the LRP by 2033 (50% probability of it occurring by 2016).

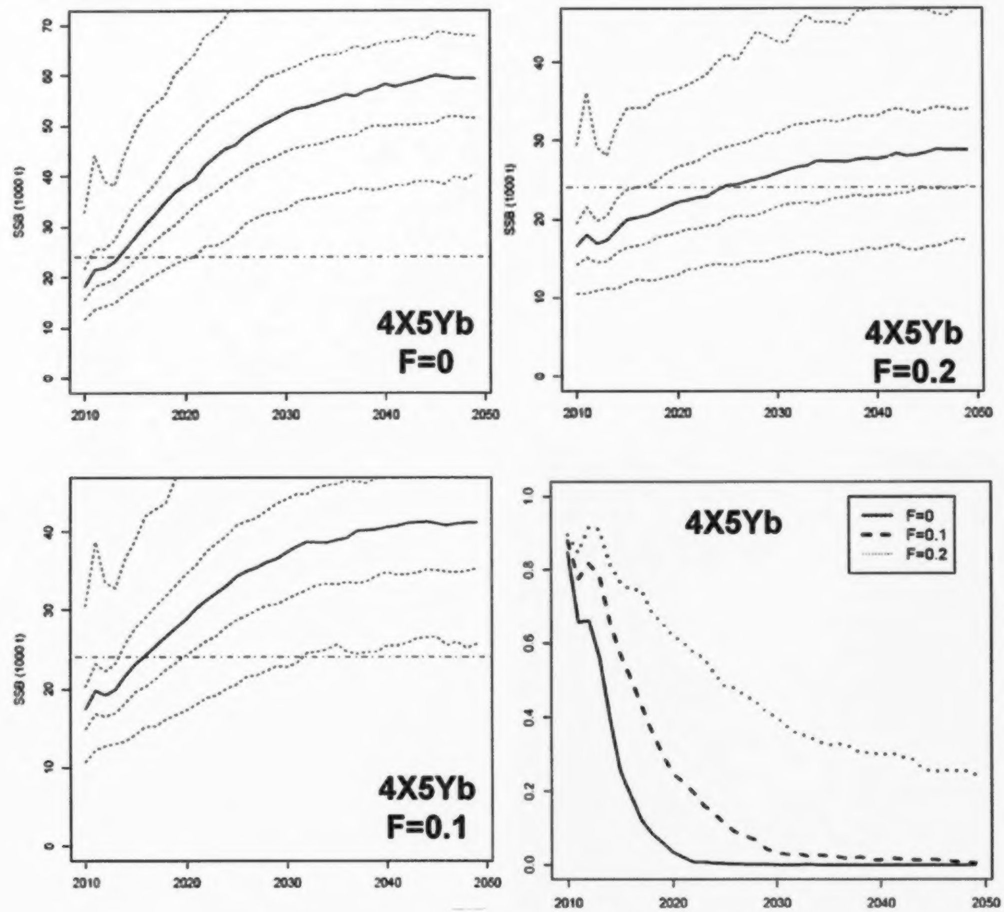


Figure 14: Projected SSB of Div. 4X5Yb cod relative to the LRP at different levels of fishing mortality, assuming that current productivity conditions were to persist in the future. Heavy lines show the median projection and light lines the 2.5th, 25th, 75th and 97.5th percentiles. The dash-dotted horizontal line in the panels labelled F=0, 0.2 and 0.1 is the LRP of 24,000t. The panel on the bottom right shows the probability that SSB is less than the LRP at three different levels of fishing.

Div. 5Zjm Cod

The 36 year projection for the 5Zjm component indicates that this component will likely recover to a level above the Precautionary Approach LRP of 21,000t. With no fishing, the median for the projection of 3+ biomass of 5Zjm cod is expected to reach the LRP of 21,000t around 2017 (2.5th percentile in 2013, 97.5th percentile in 2028) (Figure 15, top left panel). With fishing at the reference level for this stock (*F*=0.18), the biomass of 5Zjm cod also increases, but at a much slower rate, and the median is projected to reach the LRP around 2027 (2.5th percentile in 2015, 97.5th percentile >2050) (Figure 15, top right panel). With fishing at half F_{ref} (*F*=0.09), the biomass of 5Zjm cod increases at a rate between *F*=0 and *F*=0.18, and the median is projected to reach the LRP around 2019 (2.5th percentile in 2013, 97.5th percentile in 2033) (Figure 15, bottom left panel).

The probability that SSB is less than the PA LRP is shown in the lower right panel of Figure 15. With no fishing, there is a greater than 95% probability of SSB being at or above the LRP by

2028. Fishing at half the current reference level, there is a greater than 95% probability of SSB being at or above the LRP by 2033 and the probability of SSB being at or above the LRP within 36 years when fishing is at the reference level of 0.18 is 82%.

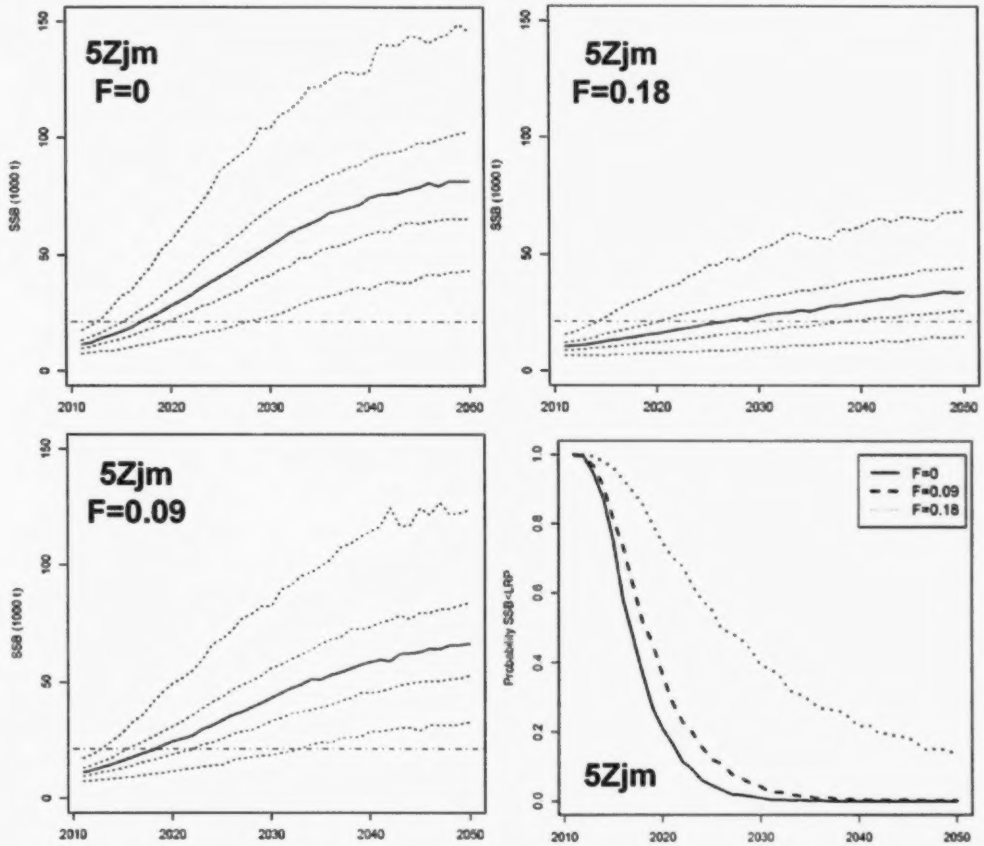


Figure 15: Projected SSB of Div. 5Zjm cod relative to the LRP at different levels of fishing mortality, assuming that current productivity conditions were to persist in the future. Heavy lines show the median projection and light lines the 2.5th, 25th, 75th and 97.5th percentiles. The dash-dotted horizontal line in the panels labelled F=0, 0.18 and 0.09 is the LRP of 21,000t. The panel on the bottom right shows the probability that SSB is less than the LRP at three different levels of fishing.

Population Projections

According to projections done under a 'no fishing' condition (*F*=0), the combined mature abundance of 4X5Yb and 5Zjm is expected to increase (given current productivity conditions) over the next 36 years. The first year of the projections in which the spawning stock number (SSN) will exceed the SSN from 36 years earlier is 2027 (Figure 16).

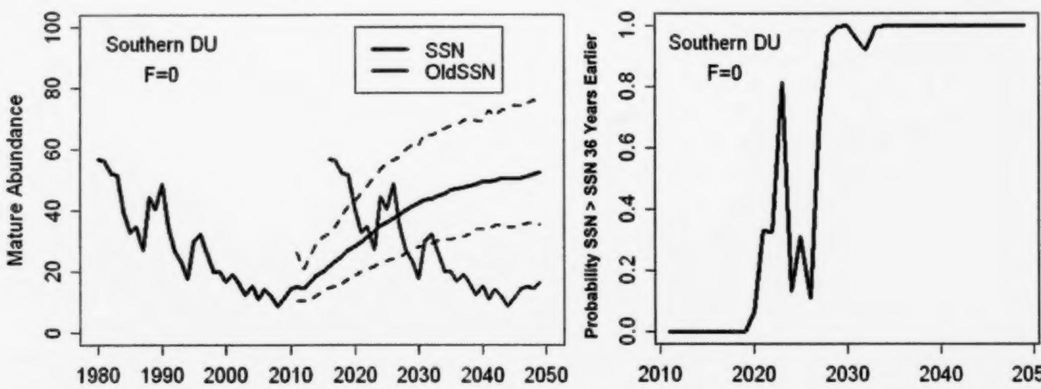


Figure 16: (Left Panel) combined mature abundance of Southern DU cod with no fishing. Solid line is estimated abundance prior to 2010, and projected abundance under F = 0. Dashed lines are 2.5th and 97.5th percentiles. The lighter solid line is for comparison purposes and shows abundance 36 years prior to each projected year. (Right Panel) probability that the SSN projected under F=0 conditions will exceed the SSN from 36 years earlier.

With projections done under fishing at F_{ref} conditions, the mature abundance of the 4X5Yb and the 5Zjm stocks is also expected to increase over the next 36 years, but at a slower rate. The first year of the projections in which the spawning stock number (SSN) will exceed the SSN from 36 years earlier is 2034 (Figure 17).

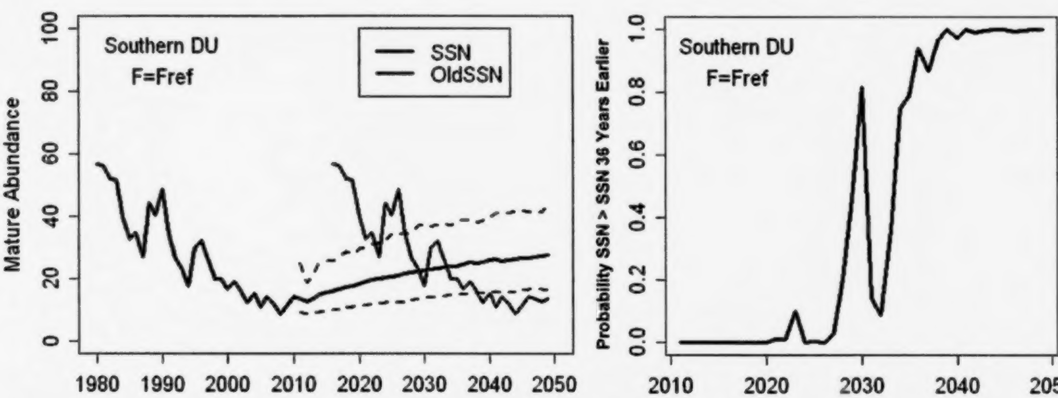


Figure 17: (Left Panel) combined mature abundance of Southern DU cod fishing at F_{ref}. Solid line is estimated abundance prior to 2010, and projected abundance under F_{ref}. Dashed lines are 2.5th and 97.5th percentiles. The lighter solid line is for comparison purposes and shows abundance 36 years prior to each projected year. (Right Panel) probability that the SSN projected under $F=F_{ref}$ conditions will exceed the SSN from 36 years earlier.

Threats to Survival and Recovery

Fishing above F_{ref}, bycatch from other fisheries, discard and natural mortality, including seal predation, are all potential threats to survival and recovery of cod in Divs. 4X5Yb and 5Zjm. In addition, COSEWIC 2010 Status Report included fishing-induced natural changes to the ecosystem and habitat alteration as potential threats.

Fishing Mortality, F

Div. 4X5Yb

Cod in Div. 4X5Yb are caught along with Haddock, Pollock, Winter Flounder, Redfish, and other species in a mixed species fishery. In the 1960s, landings of Div. 4X5Yb cod increased as domestic and foreign otter trawl fleets joined the fishery, and then dropped in 1970 as effort declined due to restrictions on haddock fishing (Figure 18, left panel). Landings averaged over 20,000t for several decades. Recent landings reflect the restrictive Total Allowable Catch (TAC). The TAC dropped to 6,000t for the 2000 quota year, then to 5,000t in 2005 and 3,000t in the 2009 quota year. In the 2009 quota year 2,900t of cod were landed in Div. 4X5Yb.

The annual fishing mortality rate (F) for Div. 4X5Yb cod is shown in the right panel of Figure 18. F has been variable but high throughout the period examined. F increased rapidly to a peak above 1.0 in 1991, and declined subsequently. F has remained above the reference level of 0.2 since 1948, and was estimated at 0.3 in 2008.

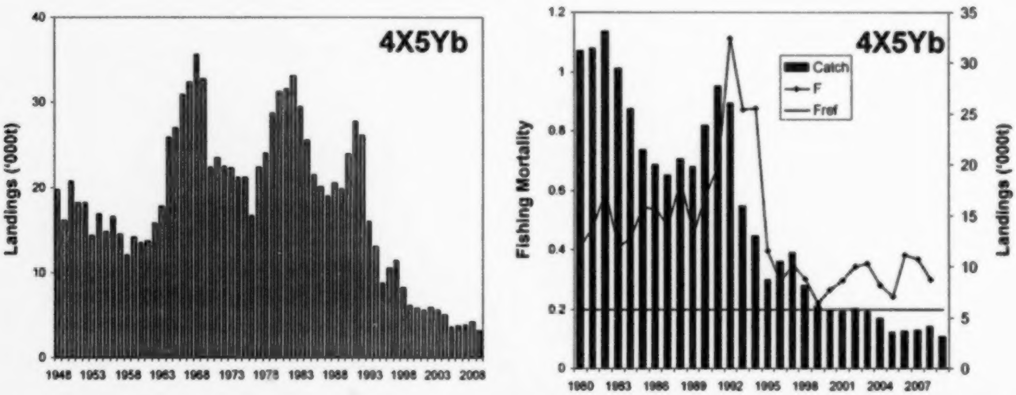


Figure 18: Catches (t) of cod from Div. 4X5Yb, 1948 to 2009 (left panel) and fishing mortality rate for ages fully recruited to the fishery (right panel). The established fishing mortality threshold reference, F_{ref}=0.2, is indicated.

Div. 5Zjm

Cod in Div. 5Zjm are also caught in a mixed groundfish fishery. Combined Canada/USA annual catches averaged 17,508t between 1978 and 1992. Catches peaked at 26,463t in 1982, and then declined to 1,684t in 1995. Catches in 2009 were 1,858t, including 425t of discards (Figure 19). Catches included discards from the USA and Canadian groundfish and scallop fleets in all years where discard estimates were available.

Fishing mortality for Div. 5Zjm cod was higher prior to 1994 and declined in 1995 to 0.24 due to restrictive management measures. Although F has not been below F_{ref}, fishing mortality has declined and is approaching the reference level of 0.18 (Figure 19). F in 2009 was estimated to be 0.20, 10% above F_{ref}.

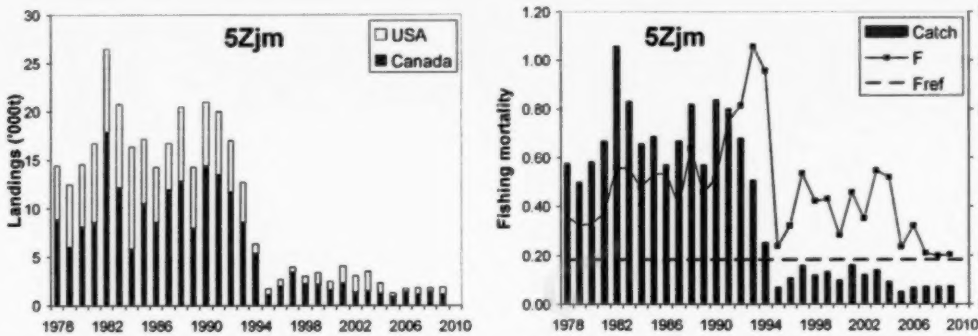


Figure 19: Catches (t) of cod from Div. 5Zjm, 1978 to 2009 (left panel) and fishing mortality rate for ages fully recruited to the fishery (right panel). The established fishing mortality threshold reference, F_{ref}=0.18, is indicated.

Discards and Bycatch

Commercial landings and at-sea observer information have been used to characterize discards from Canadian commercial fisheries conducted in 4X5Yb and 5Zjm from 2002 to 2006. Although the levels of observer coverage were generally low and intermittent, estimated discards from all non-groundfish fisheries were in the range of 20t.

Historically, the observer coverage of the groundfish fleet in Div. 4X5Yb has been below 1%, too low for any meaningful calculations of bycatch or discarding. One year of augmented observer coverage of the groundfish fishery in 4X5Yb, the 4X inshore lobster fishery and the Bay of Fundy scallop fishery has been funded by the Species at Risk Coordination/ Espèces en Péril Committee (SARCEP). The data collection and analyses are not yet complete and, thus, no precise discard estimates are available.

Observer coverage is higher in Div. 5Zjm than in 4X5Yb and discards of cod from the Eastern Georges Bank groundfish and scallop fisheries are routinely calculated and included in the 5Zjm cod assessment by Canada and the USA. Annual estimated discards from the Canadian scallop fishery range from 36 to 200t whilst those estimated from the Canadian groundfish fishery in recent years range from 0 to 237t. Annual combined estimates for discards by the USA groundfish and scallop fleets range from 0 to 341t.

Natural Mortality, *M*

Historically, a value of 0.2 has been used as an estimate of natural mortality at all ages for cod in both Div. 4X5Yb and 5Zjm. The accepted VPA formulation for the Div. 4X5Yb component of the Southern DU estimates an increase of *M* from 0.2 to 0.76 for cod ages 4+ since 1996. The VPA formulation for the 5Zjm component of the Southern DU used in this RPA also has an increase of *M* from 0.2 to 0.5 for cod ages 6+ since 1994. The high natural mortality restricts productivity and the population will not sustain fishery removals of the magnitude seen prior to 1994 unless the natural mortality rate declines.

Seal Predation

An increase in seal populations may contribute to the higher values of natural mortality in Div. 4X5Yb. Grey seal abundance has increased in recent decades on Sable Island and grey seal colonies have been established in the 4X5Y area in recent years, whilst the abundance of

harbour and gray seals have all increased in the Gulf of Maine. However, the degree to which seals contribute to the natural mortality of cod in 4X5Yb or 5Z needs to be quantified.

Other Sources of Mortality

The COSEWIC 2010 Status Report includes fishing-induced natural changes to the ecosystem and habitat alteration as potential threats. The impact of these threats on productivity of cod in the Southern DU is unknown.

Measures for Promoting Recovery

Mitigation and Alternatives to Activities

The major potential sources of mortality identified for Southern DU cod were natural mortality, including seal predation, along with directed fishing, discards and bycatch.

Directed Fishing

Mitigation measures for reducing directed fishing mortality include: the implementation of the Precautionary Approach (PA); the inclusion of harvest control rules and decisions compliant with the PA in the Integrated Fisheries Management Plans for all cod stocks; catch limits for commercial, index or stewardship fisheries; creating zones to protect high concentrations of individuals; limiting participants and/or fishing effort by restricting the number of boats or gear allowed; and, maintaining or creating no fishing zones during certain times of the year in areas where cod spawn.

A number of these mitigation measures are already being considered or have been applied in the Southern DU, including seasonal closures on Georges Bank and Browns Bank to protect spawning cod.

Bycatch and Discards

Cod in Divs. 4X5Yb and 5Zjm are harvested as part of a mixed species groundfish fishery, and are not necessarily caught in proportion to their relative abundance. This may cause an imbalance in quotas, which creates potential for discarding. Several other fisheries are known to catch cod as bycatch in the Southern DU but may or may not be permitted to land cod. Mitigation measures for reducing bycatch and discards of cod include: the application of Bycatch and Small Fish Protocols; measures included in Conservation Harvesting Plans such as gear type, mesh size, percent or weight of allowable incidental catches per trip in certain areas or during certain time of the year; adopting more stringent requirements for the management, control and monitoring of bycatch in other commercial fisheries; increasing at-sea observer coverage when (and where) the catch and discarding of fish is likely to be high to improve estimates of bycatch and discards; conducting a review, in conjunction with industry, of additional measures such as seasonal closures or gear restrictions to address the discarding of fish; recording discards in monitoring documents; increased compliance monitoring activities (such as Dockside Inspections, At-Sea Inspections, expanded use of Vessel Monitoring Systems and Aerial Surveillance).

Some of these mitigation measures, including increased observer coverage and time/area closures for the offshore scallop fishery during the Georges Bank cod spawning season, are already used in the Southern DU as methods to monitor and/or decrease bycatch and discarding. In addition, the mobile gear sector of the Div. 5Zjm groundfish fishery has employed

a mitigation measure in the form of a separator panel in order to decrease cod catches. The use of a separator panel is now mandatory for members of the mobile gear fleet fishing on Georges Bank.

Natural Mortality

High recent natural mortality is considered to be a high risk for both stocks of the Southern DU.

Seal Predation

One factor contributing to high natural mortality is increased seal predation. An increase in seal populations may contribute to the high natural mortality in Div. 4X5Yb. However, the degree to which seals contribute to the natural mortality of cod in 4X5Yb or 5Zjm has yet to be quantified and, thus, it is not known if a seal removal would help rebuild these cod stocks and decrease the risk of this threat.

Activities that Could Increase Survivorship

Reductions in directed fishing at least to the level of F_{ref}, and bycatch mortality are the only identified mitigation measures that could increase survivorship. The effect of reduced fishing mortality, which incorporates both directed fishing and bycatch, is discussed under SARA and Management Considerations. Whilst natural mortality is higher on older fish than fishing mortality, there is no identified mechanism for reducing M.

Allowable Harm Assessment

According to the projections discussed in the SARA and Management Considerations section of this document, cod in the Southern DU (Div. 4X5Yb and Div. 5Zjm) will increase in abundance in the absence of fishing and have a high probability of increasing at moderate fishing levels (i.e. F_{ref}). Allowable harm assessment indicators for individual stocks and the combined DU are summarized in Table 1.

Table 1: Summary of status indicators for allowable harm assessment for each stock within the Southern DU.

	4X5Yb Cod: B_{lim} (24,000t), F_{ref} = 0.20			5Zjm Cod: B_{lim} (21,000t), F_{ref} = 0.18		
		Years to Reach B_{lim}			Years to Reach B_{lim}	
Reduction in Fishing Mortality (F_{ref})	Probability of no decline in abundance over 36 years	with 50% Certainty	with 95% Certainty	Probability of no decline in abundance over 36 years	with 50% Certainty	with 95% Certainty
0	77.4%	14	>36	68.1%	16	>36
50%	97.4%	5	23	98.1%	8	22
100%	99.9%	3	10	99.8%	6	17

Sources of Uncertainty

The projections at either the stock or DU level are subject to the uncertainties common to stock assessment: the uncertainty in the current stock size and the factors affecting productivity. These projections differ though from the projections usually seen in stock assessments because of the requirement to project for 36 years. The factors affecting production (e.g. reproduction, mortality, growth) have been seen to vary over time and are difficult to predict. However, they tend to change slowly and the recent past is probably the best indication of the near future. The level of uncertainty increases as projections move further into the future.

The projections assist in evaluating the consequences of alternative management measures by providing a general measure of the uncertainties. However, they are dependent on the data and model assumptions and do not include uncertainty due to variations in stock-recruit relationships, partial recruitment to the fishery, natural mortality outside of what has been observed, systematic errors in data reporting or the possibility that the model may not reflect stock dynamics closely enough.

The effects of large scale environmental change on species productivity are unknown. The results of the projections would not be robust to such changes.

Combining components of the Southern DU may overshadow individual component trends. As the components sometimes exhibit differing trends, management decisions may not have the expected effect on all involved stocks.

Possible causes of recent increases in natural mortality are poorly understood. Misreporting and cod discards may contribute to natural mortality, but industry reports of such events have decreased since 2002 and calculations of cod discards from the groundfish fishery are already routinely included in the 5Zjm cod assessment. There is no evidence of a decline in fish condition which would impact on natural mortality. Although seal populations in 4X are growing, and seals are known to consume cod, the extent of their contribution to natural mortality in the Southern DU is also unknown.

Knowledge of the amount and spatial distribution of available habitat for demersal juvenile Atlantic Cod is currently unavailable at the spatial scales with which juveniles are likely to be using it. The spatial resolution of most of our available seabed habitat knowledge is on the order of tens of kilometers. In contrast, demersal juvenile cod are known to associate with seabed habitats at scales of hundreds of meters and less – a mismatch on the order of 100 to 1 in scope at best, especially in the offshore. Therefore, it is not known how much habitat is available for juvenile cod at present.

SOURCES OF INFORMATION

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Zonal Advisory Process, February 21-25, 2011 on Recovery Potential Assessment (RPA) for Atlantic Cod (Newfoundland and Labrador, Laurentian North, Laurentian South, Southern Designatable Units). Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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FOR MORE INFORMATION

Contact: Donald Clark, Kirsten Clark
Fisheries and Oceans Canada
St. Andrews Biological Station
531 Brandy Cove Road
St. Andrews, NB
E5B 2L9
Telephone: (506) 529-5908, 529-5928
Fax: (506) 529-5682
E-Mail: Don.Clark@dfo-mpo.gc.ca, Kirsten.Clark@dfo-mpo.gc.ca

This report is available from the:

Centre for Science Advice,
Maritimes Region
Department of Fisheries and Oceans
P.O. Box 1006, Stn. B203
Dartmouth, Nova Scotia
Canada B2Y 4A2

Phone number: 902-426-7070
Fax: 902-426-5435
e-mail address: XMARMRAP@mar.dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas

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